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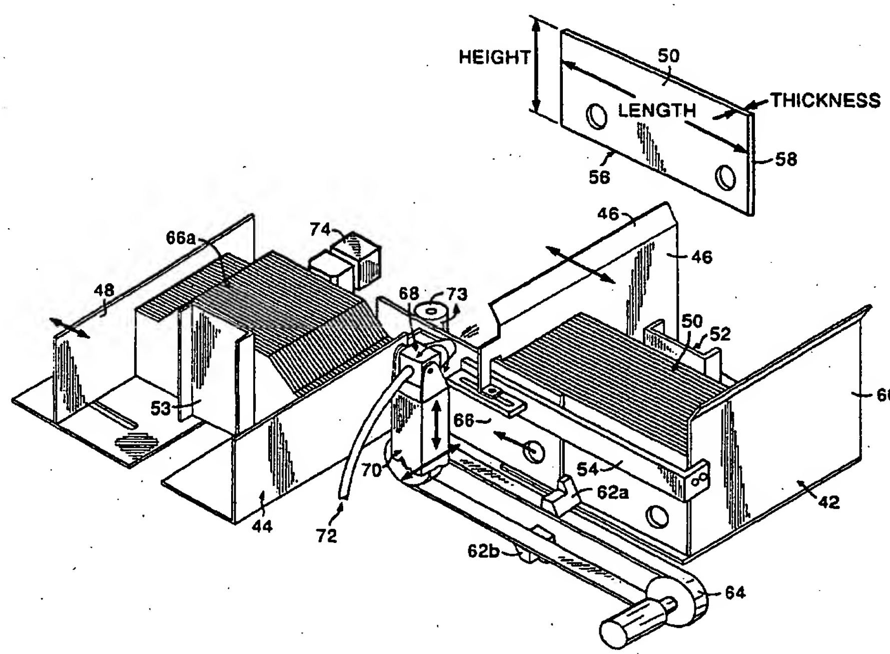

(57) Abstract

A process of forming a profiled edge lamination die is disclosed. An apparatus for use in the process and the die produced thereby are also disclosed.

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PROCESS FOR RAPIDLY FORMING LAMINATED DIES AND SAID DIES

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BACKGROUND OF THE INVENTION

Products made by sheet-metal forming processes are everywhere. They include car body panels, kitchen appliance shells, cooking utensils, and modern office furniture. Sheet metal parts are typically made by deforming a flat metal blank between two matched dies, a male and female. Oftentimes, rubber forming or hydroforming is used instead of matched die forming. In rubber-forming, the female die is typically made out of a hard polyurethane. In hydroforming, the female die is a rubber bladder filled with pressurized hydraulic fluid. Regardless of whether one or two dies are required for producing a part, the development of the correct die shape is complicated by the inherent springback of the material due to elastic recovery as well as the change of shape in the stamped part after its edges are trimmed and residual forming stresses are relieved. Thus, development of sheet metal dies is both time-consuming and expensive. For example, the development of production stamping dies for a car body panel can take up 18 months and cost up to $2,000,000. Consequently, the sheet metal forming sector in industry has expressed a need for the reduction of lead time and investment cost in die development.

Many different methods are used to fabricate sheet-metal forming dies. In industry, current methods that are used to form dies include computer numerical control (CNC) machining of a block of metal, casting the shape (usually of cast iron, steel or a zinc alloy), "burning" the shape in a metal block using electro-discharge machining, and stacking and bonding contoured laminations (thin plates) to form a topographical surface; e.g., laminated-object manufacturing. New methods for die fabrication that are being developed are a reconfigurable matrix of square

pins and surfaces constructed with thin bonded layers of ceramic or metal powder, e.g. 3-D printing and selective laser sintering.

More specifically, the most widely used method of die fabrication is by machining the required 3-D die shape into a block of metal using a 3 to 5-axis CNC milling machine (CNC die) and then polishing the surface. This method typically involves a large removal of material (hogging operation) to get the rough die shape and then one or more finely-spaced finishing passes with a ball end mill and/or a polishing tool to achieve a smooth surface. Cutting tool strength and hardness, and the maximum speed of a milling machine's axes and spindle limit the speed of the machining process. The size of the die that can be machined is also limited by the work volume of the CNC.

Casting a die and polishing the forming surface (cast die) is similar to the CNC method except that the rough shape is not created by a hogging operation. Instead, a full-size die model (usually made of wood, wax, hard clay, or plastic) is used to create a mold (made of sand, plaster of Paris, or a ceramic material) which is used for casting a solid or composite-type die. Once the die is cast, the forming surface must be finish machined or polished before it is suitable for stamping metal parts. Casting takes longer than CNC machining because of the die model that must be made, the fabrication time of the mold, the time to cast the die, and the finishing and polishing operations. Also, casting requires both foundry capabilities and a CNC machining center.

A die can be created by electro-discharge machining (EDM die) a block of metal. This is known as "die-sinking" in the sheet metal stamping industry. A full-size die-shaped electrode is "burned" into a piece of die material that is submerged in a dielectric bath. Both the electrode and the die wear away as the electro-erosion progresses so that a low erosion material such as graphite or copper-graphite is typically used for the electrode. The resulting shape after this machining operation

is the desired die. The quality of the machined surface is dependent upon the electrical current, voltage, and spark frequency. Since the die surface is usually pitted from the electrical sparks, a finish machining or polishing operation (hand-working or CNC machining) is required before these dies can be used for stamping.

A die can be fabricated by the deposition of thin layers of metal powder which are bonded to each other (similar to photo polymers in stereolithography). Two such rapid-prototyping methods are 3D printing and selective laser sintering (SLS). Three-dimensional printing, builds up a shape by repetitively spreading a layer of iron powder and selectively joining the powder within the layer by ink-jet printing of a binder material. The printed 3-D shape is then sintered in a high temperature oven (resulting in a decrease in volume) yielding a porous iron preform. Another type of metal (such as copper) can be infiltrated into the sintered iron preform rendering it non-porous to improve its structural properties. Selective laser sintering creates dies in a similar fashion except that instead of using a binder material, the layer of metal powder is selectively joined by sintering the particles with a high-powered laser. With either a 3-D printed or an SLS die, the forming surface still requires a polishing operation.

Prototype dies are oftentimes fabricated by stacking and bonding contoured laminations on top of each other to form a topographical-type surface (contoured-lamination die). Usually the contoured edges are not beveled so that the step between adjacent laminations creates a discontinuous surface. For thick laminations, either an interpolator must be used (e.g. filler epoxy) to fill in the steps and smooth the surface or the discontinuous surface must be CNC-machined smooth. The approximation of the true surface gets better as the laminations get thinner. Each lamination is machined out of flat stock using a 3-axis CNC machine with either a milling head or a laser cutter. Stacking and bonding these machined laminations is a

laborious operation because of the difficulties in registration of each layer. Currently, a rapid prototyping device known as a laminated-object manufacturing (LOM) machine creates laminated models out of thin material, but dies of this sort are not suitable for most sheet metal forming applications.

A sheet metal die can also be created with a clamped matrix of equal length square pins with rounded ends (pin die). Any 3-D surface can be approximated with the pins by individually setting each pin (pushing it out the correct distance). In essence, the pin die is an infinitely variable die which doesn't require any removal of material when the surface is created. The surface set-up speed is a function of the size of the pins (resolution) and the method used to set the tool. After setting the pins, the matrix in the die is clamped from one side with a high enough force to essentially create a rigid forming tool. Although the concept of a "universal" die made of pins is appealing to many in industry, this method is plagued by problems which include the difficulty in setting small pins, non-uniform clamping of pins, and a need for a thick interpolating material (e.g. ethylene vinyl acetate) between the pins and the sheet metal to avoid surface dimpling.

DISCLOSURE OF THE INVENTION

The present invention is directed to an improved process for producing a die, particularly a sheet metal die. Generally, the process comprises the steps of:

(1) designing a 3-dimensional model of the top surface of a die;

(2) dividing the model into a plurality of model lamination members, each of which comprises a vertical cross section of the model such that each model lamination member has a top edge corresponding to a portion of the top surface model of the die;

(3) determining the contour of the top edge of each of the plurality of model lamination members so that a die lamination member for each such model lamination members may be formed;

(4) forming a plurality of die lamination members from blank

lamination members so that the contour of the top edge of each of the die lamination members substantially corresponds to the contour of the top edge of the corresponding model lamination member; and

(5) forming from the plurality of die lamination members a die having substantially the same top surface contours as the model of the top surface of the die with the top edges of the plurality of the die lamination members in the aggregate forming the top surface of the so formed die.

While the method described herein may be carried out using any suitable lamination blank cutting device, it is particularly preferred to employ an apparatus which enables the method described herein to be carried out in a relatively fast and efficient manner. The apparatus is designed to continuously cut the blank lamination members one-by-one to form a contoured top edge on the lamination member and thereby form die lamination members. The apparatus stores the die lamination members after they have been cut in a side-by-side stacked array to form a die by clamping together the lamination members. Generally, the apparatus comprises a device for cutting lamination blanks, a means for advancing lamination blanks one-by-one past the cutting device, a means for placing lamination blanks one-by-one on the advancing means, and a receiving container disposed adjacent the advancing means, which container receives the cut die lamination members and stores them in a side-by-side vertical stacked array so as to form a die. More specifically, the apparatus comprises a loading container, a sliding guide disposed adjacent to the loading container, a means for placing lamination blanks, one-by-one, onto the sliding guide, a means for advancing a lamination blank along the sliding guide, a laser cutting device disposed adjacent the sliding guide so that a lamination blank advancing along the sliding guide passes in front of the laser cutting device and a means for disposing a die lamination that has advanced completely past the laser cutting device and has been cut into a receiving container. The disposing means works simultaneously with the placing means so that when a cut

lamination is disposed in the receiving container another lamination blank is simultaneously placed in the sliding guide.

The die produced according to the process of the present invention, which will be referred to herein as a profiled edge lamination (PEL) die, generally comprises a plurality of die lamination members, each die lamination member being substantially planar and each being disposed in a vertical plane and stacked together side- by-side in an array. The die lamination members may be held together in a stacked array by any suitable means, but preferably a clamping device. No adhesive or other means for holding the plurality of die lamination together is required. The PEL die can be made into a solid die apart from this process by some suitable means (e.g. diffusion bonding metal lamination members together) if needed or desired. Generally at least a portion of the die lamination members have a continuously changing beveled top edge. When placed together in a vertical stacked array the top edges of the die lamination members, in the aggregate, form the contoured top surface of the die.

The process for forming the die of the present invention offers a number of advantages over the prior art processes. The speed at which a sheet metal die can be fabricated is very important because it directly reduces the lead-time of die development. CNC, cast, and EDM dies take one or more days (sometimes weeks) to fabricate since a CNC die requires removal of a large amount of material (hogging), a cast die requires a master model, and an EDM die needs an electrode, and all three require polishing. Three-dimensional printing takes several hours to fabricate complicated 3-D surfaces in small dies (longer in large dies). Machining and assembling contoured laminations takes longer than profiled laminations of similar thickness because of the more complicated handling system required. The time required to set a pin die depends on the complexity of the mechanism used but it's on the same order as the contoured-lamination dies. A PEL die takes the least time to fabricate

when compared with these prior art processes; on the order of only about 30 minutes for a 0.3 meter square die. Such quick machining is accomplished by combining fast laser cutting and a quick handling system.

The shape of a newly fabricated die is a first attempt at trying to form the correct part shape. The initial die almost always needs modification as dictated by the knowledge of the die maker or by some form of closed-loop control. This is a fairly difficult and lengthy task with prior art dies since they must be hand-worked (grinding, welding, etc.) or fixtured on the bed of a CNC milling center so that the surface can be remachined. With a pin die, the matrix must be reset (which isn't nearly as time-consuming as re-machining the entire surface) and then interpolated. There are two options when a PEL die has to be modified. All the die laminations can be recut which will take no longer than resetting a pin die or individual laminations can be replaced (taking even less time) if only localized modification is needed.

The expandability of die forming area using a certain method determines how large a part that can be stamped. For CNC and cast dies, the die forming area is limited by the size of the milling machine x and y-axis travel (around 1.25 x 0.75 meters for large machines). Electro-discharge machining is usually limited to small dies (about 0.3 x 0.3 meters). Dies made by rapid-prototyping methods are limited to about 0.5 x 0.5 meters with currently-available machines.

The laminations which make up a contoured-lamination die require at least a 3-axis laser cutter for non-beveled edges and a 5-axis machine for beveled edges. The maximum work area of currently available laser cutters is about 3 x 2 meters. In addition, a CNC machining center is often needed to machine the discontinuous surface of the contoured-lamination die. A 0.3 x 0.3 meter pin die has been demonstrated but nothing larger has been found suitable due to pin clamping problems.

The apparatus used to create the PEL die has an inherent advantage over these other methods because the cutting head only has to move along the z-axis (about 0.3 meters range) and be rotated about the y-axis while the lamination blanks are advanced past the laser nozzle. The lamination handling system (y-axis) is the only part of the apparatus that need be increased to produce larger dies unlike the prior art die forming machines (machining center, CNC laser cutter, etc.) which require the travel of at least 2-axes to be lengthened. Due to the unlimited length of a die lamination and the unlimited number of laminations that can be in a die array, any die size is easily attainable.

The smoother the surface finish is on a sheet metal die, the better the finish is on the formed part. CNC, cast, and EDM dies are polished to a very smooth finish, although it takes a considerable amount of time. The surface finish of a 3-D printed die is dependent on the thickness of the deposited layers. If the surface of the die isn't smooth enough, it can be polished or a thin interpolating layer can be used. Dies formed with pin arrays or contoured laminations without bevels require thick layers of elastomer or plastic to interpolate their rough surfaces. Due to this relatively soft interpolating layer, the resulting die surface during stamping is not explicitly known and there is even a risk of interpolator failure. The PEL die of the present invention has a nearly continuous surface like the CNC, cast, and EDM dies because of the beveled edges. Although generally not the case, if the PEL die surface is not smooth enough for a specific product, either a thin (around 0.1 mm) interpolator layer consisting of Teflon fluoropolymer or other suitable material may be used or the die surface may be polished.

Die clamping is required for dies made up of discrete elements such as pins or plates. Contoured-lamination dies require clamping along the z-axis (unless the plates are epoxied or diffusion bonded together) and pin dies require high clamping forces from one side of the matrix and might even require a

backing material. PEL dies, although not solid, only require side clamping which is out of the way of the forming area and can be done by a simple clamp assembly.

Accordingly, the PEL die excels over all the other prior art methods in the areas of forming area expandability, speed of die fabrication, and speed of die modification, while still providing an adequate surface finish.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1-3, 4, 4a and 4b are perspective views of top surface models of the die and portions thereof of this invention.

Fig. 5 is a perspective view of a computer animation of a model lamination member used in the process of this invention.

Figs. 6a, 7a, and 8a are perspective views of cutting devices used in the process of this invention.

Figs. 6b, 7b, and 8b are respective side views of portions of the Figs. 6a, 7a, and 8a cutting devices showing a cutting of a lamination blank.

Fig. 9 is a perspective view of a die forming apparatus in accordance with this invention.

Figs. 9a and 9b illustrate details of the slider timing belt.

Fig. 10 is a perspective view of a die of this invention.

Figs. 11 and 12 are perspective views of other dies of this invention.

Fig. 13 is a perspective view of another die of the invention.

Fig. 14 is a perspective view of a die lamination member of

the die of Fig. 13.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

The process for forming a PEL die according to the present invention can best be described with reference to the drawings. As best shown in Fig. 1, the first step in the process comprises forming a 3-dimensional model 10 of the top surface of the die to be formed. This 3-dimensional surface will correspond to the surface contours of a product to be "stamped" or formed from the die. The 3-dimensional model is preferably produced as a meshed-in surface created in a computer aided design (CAD) program by a die designer. As shown in Fig. 1, if this 3-dimensional surface is intersected with a y-z cutting plane 12 positioned through a certain point on the x-axis, a 2-dimensional curve results. Furthermore, if the y-z plane is repositioned along the x-axis by constant increments, such as 1 mm, the collection of curves 14 produced by each of the same plane/surface intersections will approximate the shape of the original 3-D surface as shown in Fig. 2. Fig. 3 illustrates that the true 3-D surface between two adjacent curves 14a and 14b can be approximated by connecting them with a bevel 15. Thus, the approximation of the entire 3-D surface gets better as the curves get closer together, i.e. as the x-increment decreases. This collection of curves serves as a database for creating a PEL die of the surface. A 3-D model of the die's top surface will typically begin as a computer-generated surface. As shown in Fig. 4, using a commercially available (or customized) CAD package like AutoCAD® or Cadkey®, an arbitrary 3-D die surface 10 consisting of geometry-defining boundaries or edges 11 is created. The surface will appear to be a collection of 3 or 4-sided patches 16 and 18, respectively. Each surface patch, defined by 3 or 4 edges 11, is then "meshed-in" as shown in Figs. 4a and 4b to give the designer a better sense of what the surface looks like. These edge-defined surfaces are usually described by a Coon's or Bezier surface patch. To define the desired bevel for each die lamination, two adjacent intersection curves of the 3-D surface and the corresponding two y-z cutting planes are determined by

means such as commercially available CAD software with rapid prototyping (.STL) formatting as in Pro-ENGINEER® CAD software. The mathematical details of these procedures can be found in a "computational geometry" textbook. For a particular die lamination, the set of (y,z) coordinates which lie on the defining curves are used by any numerically-controlled profile-cutting machine to cut the desired beveled edge. Fig. 5 illustrates a necessary set of coordinates which are used to cut the lamination members.

After determining the contour of the top edge of all of the model lamination members of a model die top surface, the die laminations corresponding to the model lamination members are formed. The CAD data base developed from the model lamination members is used to control the cutting of lamination blanks. The formation of the die lamination members may be accomplished by any of a number of techniques. One method, shown in Figs. 6a and 6b, involves fixing a lamination blank 20 to the bed of a 4-axis CNC milling machine 21 (x, y, z-translation and y-axis rotation) so that a bevel 22 can be cut with the flute-edge of an end mill 23. The minimum radius of the die lamination profile about the x-axis is limited by the radius of the end mill. Another method shown in Figs. 7a and 7b involves using a 3-axis CNC milling machine 25 with a large diameter ball end mill 26 rapidly rotating to machine the bevels 27. Again, the minimum radius of the lamination about the x-axis is limited by the ball radius. As shown in Fig. 7b, the position of the ball end mill 26 with respect to the fixed lamination blank 28 determines both the z-height and the bevel angle of the die lamination member. To avoid excessive tool wear and breakage, the maximum cutter speed and feedrate at which lamination blanks can be machined using either one of these methods is limited by the lamination material and the cutter hardness. The numerically controlled cutting devices shown in Fig. 6a, 6b, 7a, and 7b are provided with the previously determined coordinates (in NC code form) needed to cut the lamination blank.

A more conventional and faster method to machine die lamination edge is shown in Figs 8a and 8b using a high-powered 4-axis laser cutter 30 with a highly focused light beam (e.g. 0.1 mm) As shown in Fig. 8a, a lamination blank 32 is placed on a movable working table 34, which moves the lamination blank in a predetermined manner past an articulated (x-translation, y-axis rotation) laser cutting head 36. With laser cutters, there is no tool wear and the maximum cutting rate through a particular material is not affected by the material hardness, only by its composition. The best suited laser for this purpose is the popular Nd:YAG type because of its ability to cut bevels. The other popular type of laser cutter, CO_2, is not well suited for cutting bevels because its longer wavelength laser beam (10.6 versus 1.06 micrometers for Nd:YAG) tends to reflect off the metal surface for angles over 10 degrees from the surface perpendicular, thereby not heating the metal sufficiently. As shown in Fig. 8b, the laser cutter has a maximum standoff distance (S) from the metal surface that must be maintained to prevent the beam from becoming unfocused and thereby not sufficiently heating the metal. A suitable controller with the predetermined coordinates computed into the controller will guide the laser cut.

Although an Nd:YAG laser cutter is the currently preferred machining method, an abrasive water-jet cutter (not shown) may also be used. Such a cutter creates a high velocity water-jet which contains abrasive particles (e.g. aluminum oxide) and which acts like a saw and to cut a narrow groove in the lamination plate. Although water-jet cutting of metal is considerably less accurate than laser cutting, it is ideal for cutting plastics, composites, and other non-metallic materials.

The presently preferred embodiment for cutting lamination blanks to form the plurality of die laminations needed to form a PEL die according to present invention is best shown in Fig. 9. Fig. 9 illustrates an apparatus for fabricating a plurality of die laminations in a continuous fashion. The apparatus

generally designated as 40 will be referred to herein as a die lamination profiling (DLP) machine.

As shown in Fig. 9, the DLP machine fabricates a PEL die in the following manner. The DLP machine 40 contains a loading container 42 and a receiving container 44. The back walls 46 and 48 of the loading and receiving containers respectively are adjustable to correspond to the length of the lamination blanks 50 and profiled edge laminations 66a. In operation, an array of die lamination blanks is placed into the loading container 42 between the loading container pusher 52 and the slide guide 54. Each rectangular lamination blank 50 has its bottom edge 56 and one side edge 58 machined flat and perpendicular to one another for registration purposes. The machined side edge 58 of each blank must be in contact with the fixed front wall 60 of the loading container 42. As best shown in Figs. 9a and 9b, a lamination pusher 62a attached to a slider timing belt 64 contacts the registration corner of a single lamination blank 66 and horizontally moves it past the vertically- moving beam delivery nozzle 68 (preferably a Nd:YAG laser) attached to the cutting head laser servo 70. The laser beam and the laser cutting gas (e.g. oxygen) is transmitted from a source (not shown) to the nozzle 68 through a flexible umbilical cord 72. The umbilical cord contains a fiber-optic cable and a gas hose to transmit the laser beam and the cutting gas. The laser servo 70 rotates and moves the laser cutting nozzle 68 towards and away from the lamination blank to allow a beveled cut to be made at the required stand- off distance of the laser.

Before the laser-cut lamination blank or PEL lamination slides into the receiving container 44, a lamination indexer 74, which is actuated by a solenoid of an air cylinder (not shown), pushes the existing PEL laminations ahead by one lamination thickness and then returns to its retracted position. Simultaneously, the receiving container retracting wall 53, actuated by motor-driven leadscrew, retracts by the same amount. This combination of motions allows a newly-cut die lamination

plate 66a to slide into the receiving container 44 with minimal resistance. A bevel corresponding to the desired 3-D surface slice is cut into the lamination as it moves past the laser nozzle 68. An optional rotating grinder head 73 (CCW rotation in Fig. 9) mounted vertically grinds any burrs of the backside of the bevelled laser cut. When the sliding die lamination 66 and pusher 62a clear the loading container 42, the loading container pusher 52, which is actuated by motor-driven leadscrew, indexes forward one lamination thickness in order to push the array up against the slide guide. Finally, the pusher 52 stops moving when the PEL lamination 66a is completely within the receiving container 44. At this point, the next pusher 62b attached to the slider timing belt 64 is positioned to begin sliding another lamination blank 50 out of the loading container 42. Since each lamination is handled in a similar fashion, the ordering of the die laminations within a die are preserved. Either blank laminations or previously cut laminations can be machined with this apparatus. The entire operation of the DLP machine including the receiving container pusher 52, the slider timing belt 64, laser nozzle servo 70, laser power supply (not shown), lamination indexer 74, and receiving container retractor 53 will be controlled by a single high speed computer. Any suitable materials may be used to form the apparatus, such as metal, composites, and high strength plastics. The majority of parts are formed from metal with the slider timing belt 64 being formed from some composite material (e.g. rubber reinforced with steel wire).

A single PEL die for rubber forming or hydroforming or a pair of PEL dies for matched die forming fabricated by the method described herein may be directly mounted to the platens of an industrial sheet metal stamping press. As best shown in Fig. 10, the resulting PEL die 74 comprises a plurality of die lamination members 75. The top surface 73 of the die is continuous in the y-direction and approximated in the x-direction. Before placing the die in a stamping press, the plurality of die laminations are secured together in a vertical array. While this may be

accomplished by any suitable technique, an example of a particularly preferred technique is shown in Figs. 11 and 12. As shown in Fig. 11, two holes are uniformly positioned in the sides of each member of the PEL die which allows a clamped PEL die assembly 82 to secure the entire array of laminations. The clamp consists of two round shafts 76 which are slightly smaller than the plate holes and are rigidly connected to a crossbar 78 at each end of the die. The free ends 76a of the shafts are threaded so that the bars 78 can be secured to the die with another crossbar 78 and two nuts 80. As shown in Fig. 12, the clamped PEL die 82 is placed on a U-shaped baseplate 84 which restrains the y-direction movement of the plurality of lamination members. The two crossbars 78 of the clamped die assembly 82 are then rigidly bolted to the base plate 84 to prevent x- direction movement and y-axis rotation of the PEL laminations. Regardless of the specific design used for the PEL die fixture, the important characteristics of a design are to provide a flat base plate for the laminations to be pushed up against during the forming operation and to constrain the array both horizontally and in rotation.

PEL dies according to this invention may be of any size used in industrial processing but will generally range in area from about 0.01 to 10 square meters. The process of the present invention is particularly suitable for forming PEL dies made of a metal. This is because the preferred method employs a laser, particularly an Nd:YAG laser, which cuts most metals. It does not, however, perform well on plastics. Plastic dies will generally be prepared using more conventional milling techniques as described above.

Because of the flexibility of the Nd:YAG laser cutter, choosing a metal die material is solely based on forming (not machining considerations) such as the required die hardness, wear characteristics, and cost. A harder die material is used to form sheet metal that is thick and/or has a high yield strength. Tough die materials are used for high wear situations like high

yield strength sheet metal or a large numbers of parts to be formed. When compared with aluminum, titanium, or copper alloys, steel is probably the most cost effective die lamination material in terms of hardness, cost of toughness, and cost ratios.

The required thickness of the laminations for a particular die is based upon many factors including the geometric detail of the die, the allowable approximation error due to the bevels, whether or not an interpolator is used, and the required strength of a single protruding lamination subjected to the expected maximum forming load at that point. Thick laminations on the order of about 2 to 6 mm may be used in stamping dies for parts with broad part details like aircraft skins and certain car body panels. Thinner laminations (between about 1 and 2 mm) may be used in stamping dies for parts with finer details and higher localized forming pressures like appliance covers (e.g. toasters), and cooking utensils. Laminations below 1 mm in thickness, e.g. 0.5 to .99 mm) would be used in stamping dies for fine part details but low forming pressures because of the potential for plate buckling or bending. Lamination thicknesses in a PEL die need not all be the same. For instance, if there is a section of a die which is of uniform cross-section or requires higher forming strength, thicker laminations may be used in the section than in the balance of the die.

The process of the present invention forms PEL dies which are usable in a variety of industrial stamping processes such as plastic thermoforming and composite lay-ups. However, it is particularly useful in forming PEL dies for use in sheet metal forming operations. In a sheet metal forming operation, a PEL die will usually be made out of thin hardened steel plates. A pair of steel dies can be created and mounted in a stamping press for matched-die forming. Many sheet metal forming processes involve only one die (male or female) which can easily be fabricated with a DLP machine. These processes include hydroforming, rubber-forming, stretch-forming, and explosive-forming. For hydroforming, rubber-forming, and explosive-

forming, the surface quality of the die is not as critical as for matched-die forming and stretch-forming because the sheet metal (usually steel and aluminum) isn't stretched over the surface as much. Therefore, a surface interpolator may not be needed in these cases.

A PEL die made of aluminum or hard plastic laminations can be used for thermoforming plastic sheet. Thermoforming involves forming thermoplastic sheet or film over a die (male or female) with the application of heat and pressure differentials. As shown in Fig. 13, the die 90 must have holes 92 from the die surface to the back of the die through which a vacuum can be drawn. This can be accomplished by machining or scratching grooves 94 in selected lamination members 96. Typical parts made with this process include advertising signs, appliance housings and liners, and packaging.

For the molding of composite materials, a single PEL die or a matched pair of dies can be used. Such a die can be made of aluminum or plastic sheet. Two conventional methods of composite forming are pressure-bag molding and vacuum-bag molding. In pressure- bag molding, a composite material is placed on a mold and pressure is applied to the lay-up with a pressurized flexible bag. Sometimes the molds are heated to accelerate the composite hardening and the dies are then mounted to heated surfaces and allowed to heat up themselves. Vacuum-bag molding involves laying prepregs, which are uncured composites in tape form, on the mold to form the desired shape. In this case, the pressure required to form the shape is obtained by covering the lay-up with a plastic bag and creating a vacuum. Typical composite pans include car fenders, appliance housings, and boat hulls.

WHAT IS CLAIMED IS:

1. A die comprising (i) a plurality of die lamination members, each die lamination member being substantially planar and each being disposed in a vertical plane, and (ii) a means for holding the vertically disposed die lamination members together.

2. The die of Claim 1, characterized in that at least a portion of the die lamination members have a continuously changing beveled top edge.

3. The die of Claims 1 and 2, characterized in that each of the die lamination members is of substantially the same thickness.

4. The die of Claims 1 and 2, characterized in that a first portion of the die lamination members have substantially a first thickness and a second portion of said members have substantially a second thickness.

5. A process for producing the die of Claims 1-4 characterized by the steps of:

(1) designing a 3-dimensional model of the top surface of the die to be formed;

(2) dividing the 3-dimensional model of the top surface into a plurality of model lamination members, each of which comprises a vertical cross section of the die top surface model characterized in that each model lamination member has a top edge corresponding to a portion of the die top surface model;

(3) determining the contour of the top edge of each of the plurality of model laminations so that a die lamination member for each such model lamination member may be formed;

(4) forming a plurality of die lamination members from blank lamination members so that the contour of the top edge of each the die lamination members substantially corresponds to the contour of the top edge of the corresponding model lamination member; and

(5) forming from the plurality of die lamination members a die having substantially the same top surface contour as the model of the top surface of the die, with the top edges of the plurality of die lamination members in the aggregate being held together to form the top surface of the so formed die.

6. The process of Claim 5, characterized in that the model of the top surface of the die is a computer aided design (CAD) drawing.

7. The process of Claim 5, characterized in that the contour of the top edge of a model lamination member is determined by calculating the coordinates of a multiplicity of sections of the top edge thereof.

8. The process of Claims 5-7, characterized in that each die lamination member is formed by cutting a blank lamination member with a cutting device which is a laser, an abrasive water-jet, or an end mill.

9. The process of Claims 5-8, characterized in that the plurality of die lamination members are formed one by one by passing the lamination blanks one by one through a die lamination profiling device containing a cutting means which cuts the lamination blanks so as to form the die lamination members.

10. The process of Claim 5, characterized in that the plurality of die lamination members are formed into the die by clamping together the plurality of die lamination members so that said members extend in a vertical plane side-by-side in a stacked array.

11. An apparatus for cutting a plurality of lamination blanks used to form the die of Claim 1 characterized by: a device for cutting lamination blanks; a means for advancing lamination blanks one-by-one past the cutting device; a means for placing lamination blanks one-by-one on the advancing means; and a

receiving container disposed adjacent the advancing means, which container receives the cut die lamination members and stores them in a side-by-side vertical stacked array so as to form a die.

12. The apparatus of Claim 11 characterized by: a lamination blank loading container; a sliding guide disposed adjacent to the loading container; a means for placing a lamination blank onto a sliding guide; a means for advancing a lamination blank along the sliding guide; a laser cutting device disposed adjacent the sliding guide so that a lamination blank advancing along the sliding guide passes in front of the laser cutting device; a means for disposing a cut lamination that has advanced completely past the laser cutting device into a receiving container; characterized in that said disposing means works simultaneously with the placing means so that when a cut lamination blank is disposed in the receiving container an uncut lamination blank is simultaneously placed on the sliding guide.

13. The apparatus of Claim 12, characterized in that the advancing means is a pusher member attached to a continuously moving timing belt.

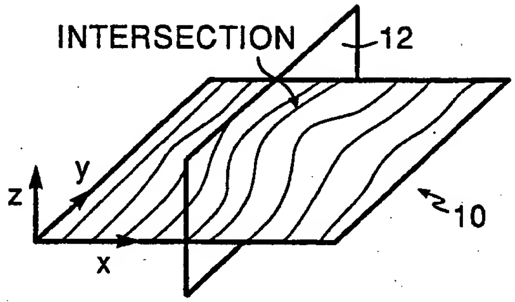

FIG. 1

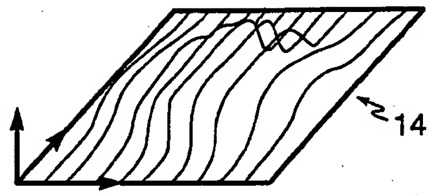

FIG. 2

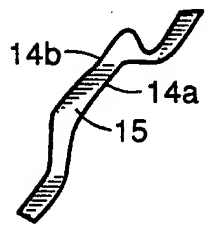

FIG. 3

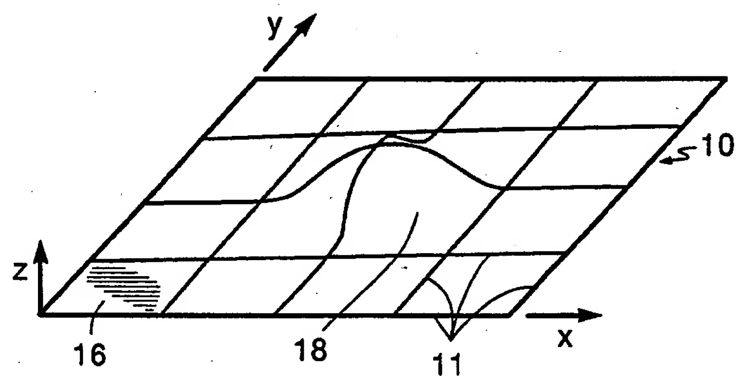

FIG. 4

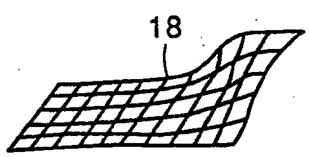

FIG. 4A

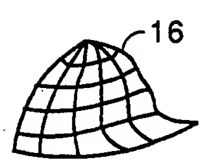

FIG. 4B

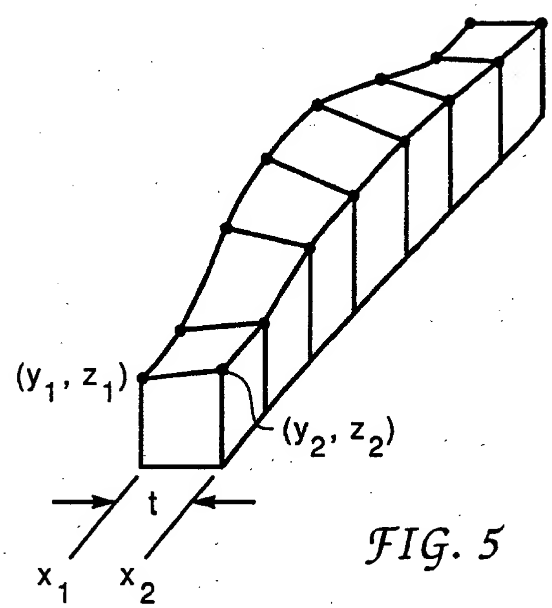

FIG. 5

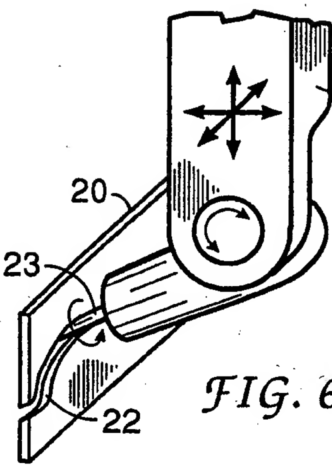

FIG. 6A

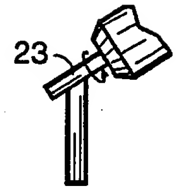

FIG. 6B

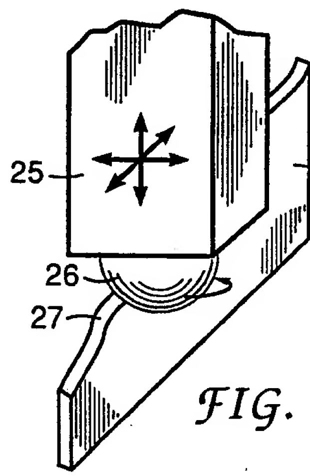

FIG. 7A

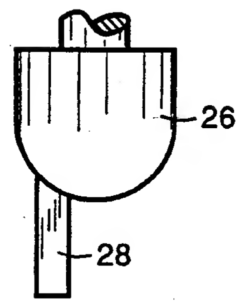

FIG. 7B

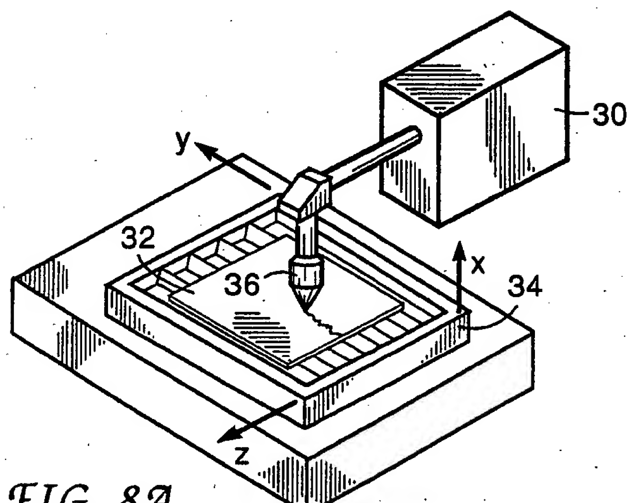

FIG. 8A

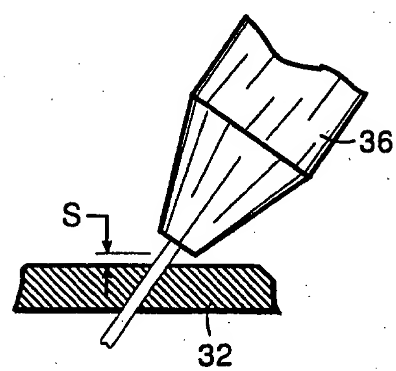

FIG. 8B

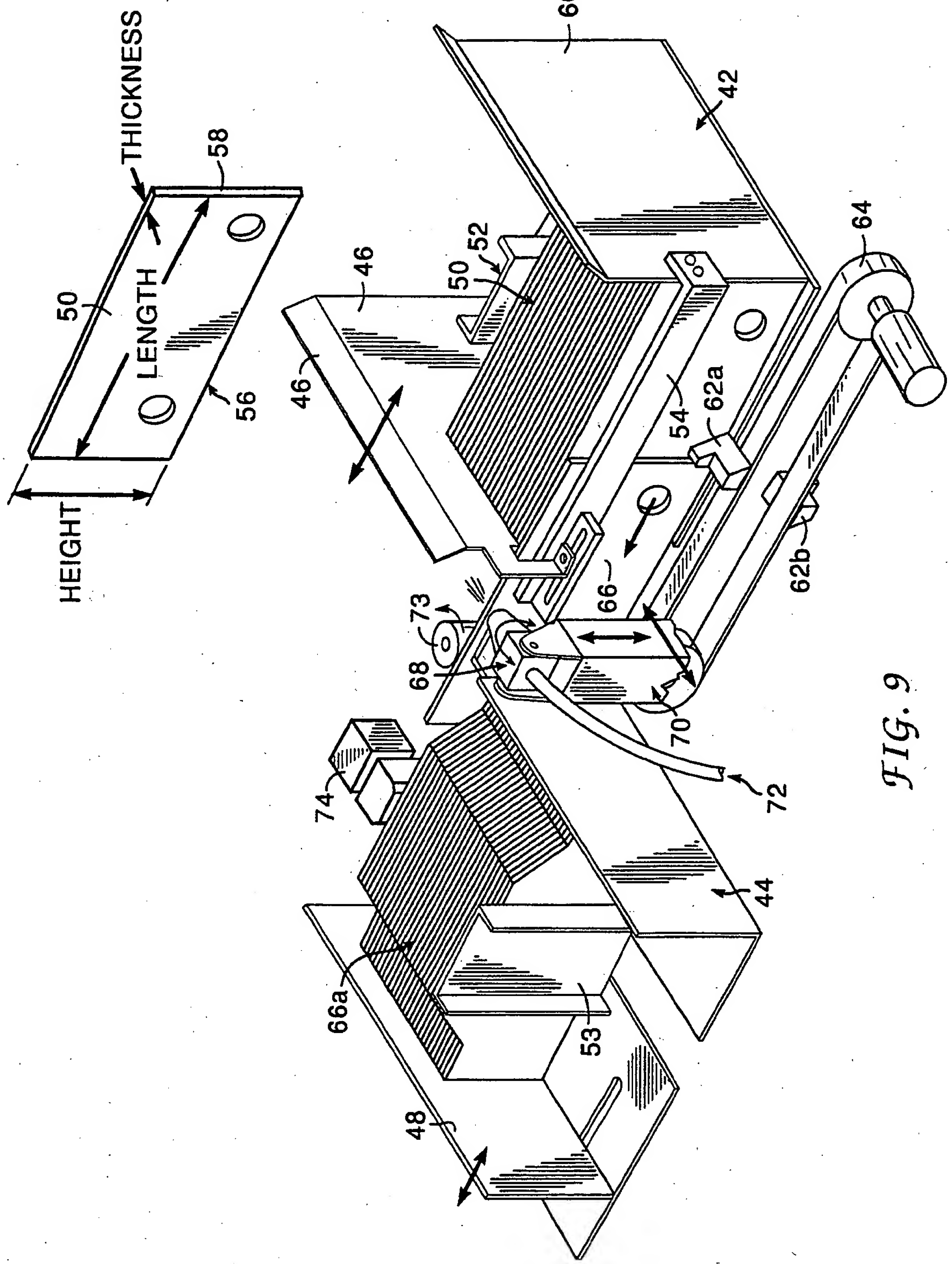
THICKNESS
58
50
LENGTH
56
HEIGHT
60
42
46
52
50
46
54
62a
64
66
62b
73
68
70
72
74
44
66a
53
48

FIG. 9

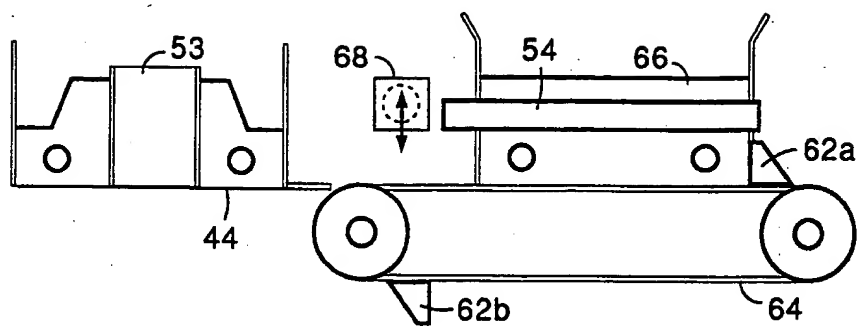

FIG. 9A

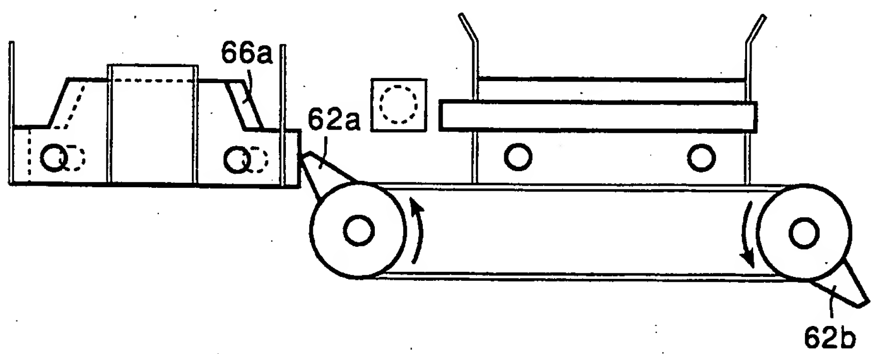

FIG. 9B

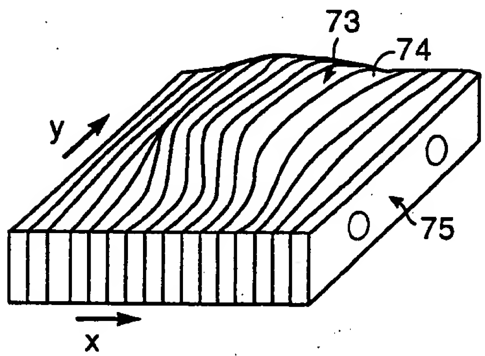

FIG. 10

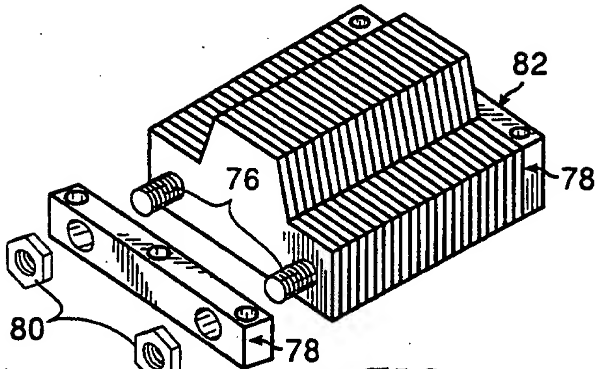

FIG. 11

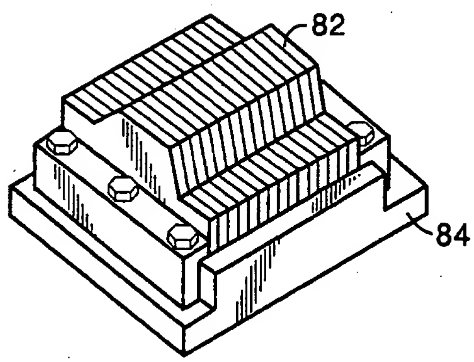

FIG. 12

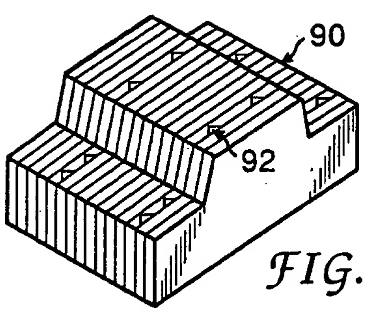

FIG. 13

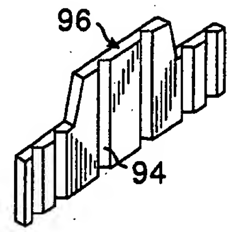

FIG. 14